

Insertion A

For example there are the positivists, who ~~were~~^{are} generally happy to be realists at the level of ^{direct} macroscopic observation, but drawing a sharp observational/theoretical distinction, treat the theoretical machinery just as a calculational device or instrument if you will, for connecting observational input with observational output, in what amounts to a black box approach to theoretical physics. To be inquisitive, seeking to get out the metaphysical 'sewer' driver, lever off the lid and see what was is going on inside, ~~was~~ rigorously prohibited.

But much of recent philosophy of science has served to throw doubt on any sharp distinction between observation and theory (the slogan here is the theory-ladenness of observation). If one is moved by these arguments one will either reject ^{metaphysical} realism even at the level of observation and move to a position such as pragmatism, where the slogan becomes, "it is true for you if it works for you." But given certain aims we may still try to retain ^{some} ~~some~~ rationality in how ^{best} to achieve those aims. Or we may be driven in the opposite direction, interpreting the theoretical machinery as well as the observations realistically.

Should we believe in Quarks and QCD?

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show ①

There are two questions I want to address in this paper.

- 1) What is the evidential status of entities such as quarks and theories such as QCD? In particular is there a special problematic associated with just these entities and this theory?

But that leads to the second question of a more general nature,

- 2) What is the evidential status of any theoretical entities and their properties and relations as encoded in some area of theoretical discourse.

The second question touches on a central concern of general philosophy of science. But let me start with the first question.

(as distinct from the literary vocabulary)

Quarks first came into the physics vocabulary via the fundamental representation of the $SU(3)$ symmetry introduced into hadronic physics in the early 1960s by Murray Gell-Mann and Yuval Ne'eman. The actual known particles were associated with higher-dimensional representations of the symmetry, such as the octet, the original eight-fold way. The quarks were at first a somewhat shadowy substratum for building up the particles actually observed in nature (in particular the famously predicted Ω^-). I say shadowy because one could, for example, abstract from them (the quarks) an algebra of currents, and take this seriously and discard the quarks - throwing away the ladder after making the ascent so to speak. But then, in the late 1960s came the deep inelastic electron scattering experiments at SLAC, the verification of Bjorken scaling, and the immediate interpretation in terms of point-like constituents, the parton model of the

nucleons. It was then a small step to identify the partons which in a sense one could directly 'see', with the highly conjectural quarks. But with the quarks came the theory of quark interactions, the colour degrees of freedom, the gluon fields and the whole apparatus of non-Abelian gauge theory in the now familiar Standard Model, augmenting the electro-weak theory of Weinberg and Salam with the quantum chromodynamics of strong interactions.

And there were immediate successes in terms of empirical predictions, quantitatively verified departures from crude Bjorken scaling, the production of jets and so on. So did physicists believe in the theory? (I will come to philosophers later.) Well, not exactly; it was not that the theory was empirically refuted, far from it, but there were theoretical puzzles that made it unattractive as the demonstrable 'last word' in the theory of strong interactions.

Firstly there are all the general puzzles about understanding and interpreting quantum mechanics. These problems however are generally brushed under the carpet, so to speak, by most physicists, but dirt under the carpet is still dirt, I would submit. Then there was the generally unsatisfactory business of infinite renormalizations. Most physicists regarded renormalized theories as some sort of 'effective theory', hiding the detail of the 'true' theory behind renormalized parameters, whose values were to be taken from experiment.

Next there was a sense of ad hocery in the number of adjustable parameters in the Standard Model, and the curious role of the Higg's particle in the electro-weak sector. Then physicists were drawn by the Holy Grail of grand unification, tying the leptons and quarks in a single scheme. Grand unified theories generally predicted the instability of the

proton, via the interconvertibility of quarks into leptons. This has not so far been observed, but ^{many} ~~most~~ physicists ^{will} expect that it is an allowed process, although on a very long time scale. To that extent they do not believe crude QCD as the final theory.

Finally there is of course the whole question of incorporating gravitation in a Theory of Everything, and the recent surge of enthusiasm for superstring theories.

So the question 'Do physicists believe in QCD?' is rather like asking 'Do physicists believe in classical mechanics?' The answer is yes for certain limited purposes of theoretical modelling of phenomena, but not in the sense that it is a serious candidate for being dead right - the final answer in strong interaction physics.

But what about the quarks themselves? There is often thought to be a special problem here associated with ~~the~~ ^{the} phenomenon of quark confinement. In the past the 'real' has been probed by the 'manifest'. Electrons, atoms, nucleons and so on could be dealt with singly in their free state, and then everything explained by an elaborate aufbau principle, putting the single elements together. This is the classical method of analysis, of understanding complex wholes in terms of their simple constituents. But in a sense the quarks are a sort of counter-example, since they cannot be separated from their partners.

But this stress on making real entities manifest is a somewhat crude rendering of what we mean by manifest. The deep inelastic scattering experiments manifest the quarks just as surely as holding them, one at a time, in the hollow of one's hand so to speak. 'Direct' observation is actually pretty 'indirect', so far as particle physics is concerned. We 'see' particles by actually seeing what they can do, producing tracks in

bubble chambers, firing off spark chambers and so on.

Let us now turn to what a philosopher might say on reading the preceding paragraphs, which are supposed to represent the views of physicists. I will therefore turn to my second question, which has a much broader focus than just quarks and QCD.

In what sense should one believe in science at all? There's a broad spectrum of what I may call isms and schisms in answering such a question which fill the pages of philosophical monographs and journals. ^{Show (2)} At one end of the spectrum there are the relativists, the anti-realists, the ^{social constructivists} irrationalists. At the other end are the realists, the objectivists, the champions of scientific rationality - and there's pretty well every shade in between. ~~* Insertion A~~

~~But~~ ^{now} Let me first sketch the extremes and then look ^{again} at the compromises. But ² ~~as we~~ shall ^{stress that} see the compromise positions generally tend to be unstable, and it is very easy to be driven to particularly one of the extremes, if one looks at the matter dispassionately. So firstly what are the arguments of the ^{out-and-out} relativist, put in the proverbial nutshell? First the relativist denies that there is an objective fact of the matter about any area of discourse, whether it be natural science, ethical questions, or even logic and mathematics. There is no Archimedian point, no God's-eye perspective, from which truth in the sense of correspondence with what is actually the case, makes any sense, and any claim to grasp 'reality' as it is in itself, the Kantian ding-an-sich, is just a metaphysical conceit.

How, say the relativists, could we achieve knowledge of this sort, either by reason, which they dismiss as ridiculous, or on the basis of empirical observation, which they say is so conditioned by theoretical presuppositions that it can provide no sure foundations for knowledge in

the old-fashioned sense of knowing the objective truth about things, what they are, how they behave and so on.

Everything is relativized to purely subjective opinions, or at best intersubjectiv~~2~~ agreement conditioned not by the world and its scientific investigation for example, but by socio-economic factors and ideologies. Truth comes out as coherence, or perhaps whatever makes us feel good, never correspondence with what is in fact the case. For example relativists can well say religion is true in their sense, but not because there actually is a God, or a moral law, and it is the same with science - 'quarks exist' is true just in case someone believes that quarks exist, or maybe because some social group, such as high-energy physicists agree that quarks exist, but never because, surprise, surprise, quarks do in fact exist. There are two conclusions that one can reach with this line of thought. Either one knows nothing, one is just a sceptic in the famous Pyrronist tradition of antiquity, or, surprisingly enough, one knows anything and everything, that one has an opinion or a belief about, because that is what a relativist means by knowing something. Of course, relativism has some apparently curious features. I know that fairies live at the bottom of my garden, if that is what I, or perhaps my local community, ^{do} believe, even if nobody else does. For the relativist, since there is no robust notion of truth, there is also no notion of error, of being wrong. To be wrong in their Pickwickian sense is just to disagree with someone else. But even that is a bad way of putting it. You are both right in your own terms and from your own point of view if Jack says there are fairies at the bottom of his garden, and Jill says there are not. Now why should we think that relativism is true? Well, in what sense of 'true'? Relativists often speak as though the truth of relativism is the one thing they can know in

the old-fashioned sense, but since they don't admit the old-fashioned sense, does the truth of relativism just dissolve into a matter of mere opinion, but then why do they bother with arguments? ^{of course} The relativists regard their position as the height of post-modernist sophistication, but in fact (~~what does that mean?~~) the whole position totters towards incoherent absurdity.

Now let us look at the other extreme, realism. This roughly denies everything that the relativist asserts. There is an objective world, quite distinct from us and our musings and imaginings, where quarks either do exist or do not exist. We may never come to know decisively which is the case, but experimental evidence can be adduced to bear on the question, to provide degrees of support or confirmation, for the claim that quarks exist. Do we know indubitably the evidential basis itself? No, not for sure, but again we can make reasonable estimates about the reliability of experimental reports, based on the usual procedures of testing and calibration.

This all sounds much closer to what the physicists said, but have we really grasped the ⁿettle of the ding-an-sich, of knowing how things really are? I believe that my old mentor Popper had the right approach to this problem. We conjecture how things are, we are never in a position to know for sure whether we are right, but the conjectures are not made in a purely fanciful or speculative way, they are subject to evidential control by the techniques of experimental science, by observation, by inspecting the world. Popper of course emphasized the negative control of refutation, and one might want to allow some more positive sense of support or confirmation. But there is some control, the world kicks back, we cannot just make it up any way that pleases us. We don't construct quarks, we

actually assess evidence for the conjecture that they do actually exist.

Now ^{Back To} what about the compromises? Well once you go soft on the notion of truth, you have started on a slippery slope. You may try to hang on to some middle ground such as pragmatism, with its talk of truth as the eventual consensus of some group of ideal enquirers, but how can we tell what makes an ideal enquirer? Could it be, cynically, just someone who ultimately comes to agree with you yourself? But the pull to extreme relativism is really impossible to resist. So the trick of not turning into a relativist is not to allow the first, subtly alluring move, of going soft on truth. For quarks it may not matter so much, but in everyday life I believe it really does make a difference whether we believe in medical science as against witchcraft and spells, and I know for sure which jetliner I want to travel in, the realist's or the relativist's!

So let us start again at the other end, and ask should we be realists about matters relating to the macroscopic world of ^{as the positivists would allow} everyday life? And if the answer seems to be yes, let us make the reverse slide, if I can put it like that, from a robust realism about tables and chairs, to a definitely more conjectural realism, but realism all the same, about quarks and QCD.

I believe the physicist's gut feeling for these things is probably right (that is another conjecture for you) and I totally reject the wishy-washy but ultimately destructive doctrines of the relativists and the social constructivists, and if that opinion is imputed to my socio-economic environment, or my pre-natal experiences in my mother's womb, I will simply respond: 'poppycock'.

apparently liberal,
open-minded and egalitarian

you may as well hang for a sheep as a lamb

So I have nailed my colours to the mast as a realist. But there are a number of issues that still need attending to.

- (1) Firstly underdetermination: there may be two or more quite distinct metaphysical accounts of the nature of reality, which have ^{exactly} the same empirical consequences. So ^{how} could experiments ever be brought to bear in ~~proving~~ selecting one account of reality rather than another?

An example that arises equally in classical physics is field versus particle accounts of the ultimate nature of matter. Consider the simplest question: how does ^{a lump of} matter ^{get} go from A to B? Show (3)
The particle account says that a substantial lump of matter, viz. the particular mode of particles just moves across from A to B. But the field theorist would say that a ^{force} field of impenetrability has changed its configuration from one concentrated around A to one concentrated around B.

But although two theories may be impossible to distinguish empirically they may further ^{quite} differ from its point of view of heuristics, i.e. one metaphysical approach may lead in a very natural manner to a succession of empirically testable theories while the other may be relatively barren from the heuristic point of view. Show (4)
This is well illustrated by the great

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fertility of the quantum field theory developments in the 1960's as compared with the rival S-matrix programme.

- (2) Realism has often been attacked on the grounds that there is a significant lack of convergence in the history of theoretical physics, which, so the argument runs, is characterized by discontinuity rather than any continuous cumulative progression.

But, I believe that detailed historical analysis often reveals much more continuity than one suspects, at any rate at the level of 'structure' rather than ontology.

(cf local ^{non-relativistic} symmetries generalizing $U(1)$ global symmetry in QED)

- (3) Realism seems to require some adequate notion of truth likeness a resemblance. Given that our theories are often discarded can we nevertheless make sense of 'approach to the truth'.
- This is a very thorny technical problem in philosophy of science, that hinges on the question: ^{Q1} What is a theory really about? For example consider an astronomer's theory that predicts the number of planets P and the number of days in the week D . Suppose it gets both these numbers wrong, but gets $P+D$ right? Should this count in

assembling whether the theory has
 got closer to the truth? This is
 a question to which no totally satisfactory
 answer has been given. Intuitively
 $P+D$ is not an interesting or significant
 quantity to get right, but how can
 we rate it on purely logical grounds?

- (4) This points to the question: are
 we supposed to be realistic
 about every aspect of a theory?
 In the case of many theories in
 mathematical physics the answer
 seems to be clearly No. The
 physical content is often embedded
 in a wider mathematical structure
 that itself has no physical content.
 Examples of such a situation might
 include the analytic S -matrix
 where axioms are introduced essentially
 the behaviour of the physical quantities
 continued analytically to the complex
 plane, or more relevantly to our
 purposes, the role of gauge transformations
 in a theory where the physically significant
 quantities are gauge-invariant.

Such developments certainly encourage
 the view that mathematical physics is
 just pieces of mathematics, a black
 box which is only connected to the
 world via its empirical predictions.
 But because some parts of a mathematical
 theory * do not have physical correlates, it does
 not follow that we should be

* what I have
 called
 the surplus
 structure
 in the
 slab

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instrumentalists about the whole structure.

- (5) I have already referred to the problems about the interpretation of quantum mechanics. Recent developments particularly associated with the work of the late John Bell, show the problems of reconciling QM with local realism. But these issues are a good deal more subtle than many physicists will allow. Realism certainly seems inconsistent to require some ~~sort~~ form of nonlocality, but this may not be of a form that makes the whole programme of interpreting QM ~~valued~~ ^{valuable} ~~inconsistent~~ ^{inconsistent} with relativity theory.

So there are certainly problems associated with the realist position. But these problems merely demonstrate that philosophy of physics is no more a finished enterprise than physics itself. They provide us with a challenge for further endeavour.